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SUBSIDENCE IN DRAINED COASTAL PEATLANDS IN SE ASIA: IMPLICATIONS FOR SUSTAINABILITY

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SUMMARY

Drainage of peatlands leads to subsidence. This often eventually leads to gravity drainage and agricultural production becoming impossible, certainly if subsidence brings the land near sea level. In this paper, we demonstrate that serious drainability problems in SE Asia will start in a few decades after drainage and may lead to the end of agricultural production in between 30% and 69% of coastal peatlands within 50 years. We propose that in land use planning and economic cost-benefit analyses, the benefits of increasing agricultural productivity on peatlands in the short term should be weighed against the inevitable increase in water management costs and loss of production in the longer term.

KEY WORDS: tropical peatlands, drainage, subsidence, water management, flooding

INTRODUCTION

Peatland drainage leads to subsidence, which in turn leads to reduced drainability, declining productivity and in lowland areas often eventually results in abandonment of land for agricultural production. There have been many documented cases around the world of subsidence exceeding 2 metres in a few decades and of subsidence over 3 metres within a century (Table 1). It is also known that the biological oxidation component of subsidence is highly temperature dependent and therefore higher in warmer climates (Table 1; Stephens et al., 1984). A number of studies confirm that subsidence rates in drained tropical peatlands in Malaysia and Indonesia are at the high end of the range found globally, at around 5 cm y^{-1} (Andriesse, 1988, Wösten 1997, DID Sarawak 2001, Hooijer et al., 2011; Hooijer et al., 2012, this conference), and report that this is caused mostly by biological oxidation with the physical processes of consolidation and compaction being major contributors to subsidence only in the first years after drainage. Due to the dominance in (sub)tropical peatlands of biological oxidation, which does not result in soil 'ripening' or 'maturation', no evidence is found of a substantial slowdown in subsidence rates in the long-term after the initial few years, until peat is depleted or lower peat layers with higher density or mineral content are accessed (Stephens et al. 1984, Hooijer et al. 2012).

Table 1 Subsidence rates in peatlands across different climate zone in the world. The highest subsidence rates are found in warmer areas.

Area (country)	**Area (km^2)***	**Drainage period (years)****	**Total subs. (m)**	**Ann. Subs. (mm/yr)**	**Av. Ann. Temp. (°C)**	**Ref.**
East Anglian Fenlands (UK)	1 276	130	3.9	30	9.0	Hutchinson, 1970
Dutch coastal plain (The Netherlands)	8 000	1000	2.0***	2	10.0	Unpublished results
Venice Watershed (Italy)	23	70	2.0	29	12.0	Camporese et al., 2006
Sacramento-San Joaquin Delta (USA)	1 000	160	1.0-8.0	6-50	15.9	Deverel & Leighton, 2010
Everglades (USA)	2 600	75	2.5	33	22.0	Stephens, 1956
Johor (Malaysia)	950	40	3.0	75	25.0	Wösten et al., 1997
* land use is foremost agriculture, with the exception of The Netherlands, where land use is pasture. **These values all include the initial drainage period, in which subsidence is dominated by consolidation ***Average value, extremes up to 5 meter, and up to 12 meter if peat mining is included						

Cumulative subsidence reported in peat in SE Asia of more than 3 metres in thickness over the first 5 years after drainage is between 1 and 1.5 metres. Over the first 25 years after drainage this is commonly around 2.5 metres. If peat depths and hydrology allow it, a loss in peat surface elevation of 6 metres is expected over 100 years, excluding the effect of fires which is a significant cause of peat loss in this region (Page et al. 2002). These numbers assume water table depths stay around 0.7 metres on average which is presently the norm in relatively well managed plantations in Indonesia (Hooijer et al. 2012). If water levels are lower, greater cumulative subsidence rates are expected; if they are higher subsidence would be reduced. However the effect of bringing up water levels is not as great as is sometimes assumed because other impacts of plantation development, especially higher soil temperatures, are also important controls on biological oxidation. Moreover, the scope for raising water levels is limited as the optimum levels for both oil palm and *Acacia*, the two main crops on tropical peatlands, are at 0.6 metres or below (DID Sarawak, 2001). Subsidence, and the accompanying loss of carbon to the atmosphere, are therefore inevitable consequences of deforesting and draining tropical peatlands.

While the subsidence caused by peatland drainage in SE Asia is well recognized and quantified, there have been no studies to date of the longer-term effects of subsidence on future land drainability and agricultural productivity. From other regions, such as East Anglia in the UK (Hutchinson, 1970; Table 1), it is known that continued subsidence often eventually leads to gravity drainage becoming impossible if subsidence brings the land near sea level. Indeed, around the world this has been a major cause of abandonment of drained peatlands. The unsustainable outcome of peatland drainage has also been described for Indonesia in past decades, generally leading to the conclusion that areas with peat over 2 metres in thickness are unsuitable for conversion to agriculture (Andriesse 1988). This has however not stopped many millions of hectares of peatland being deforested and drained since 1990. In this paper, we assess how serious the problem of production loss on drained peatlands in SE Asia may become, by tentatively estimating the minimum area that may be at risk of loss of drainability or inundation, as well as the time that this development may take.

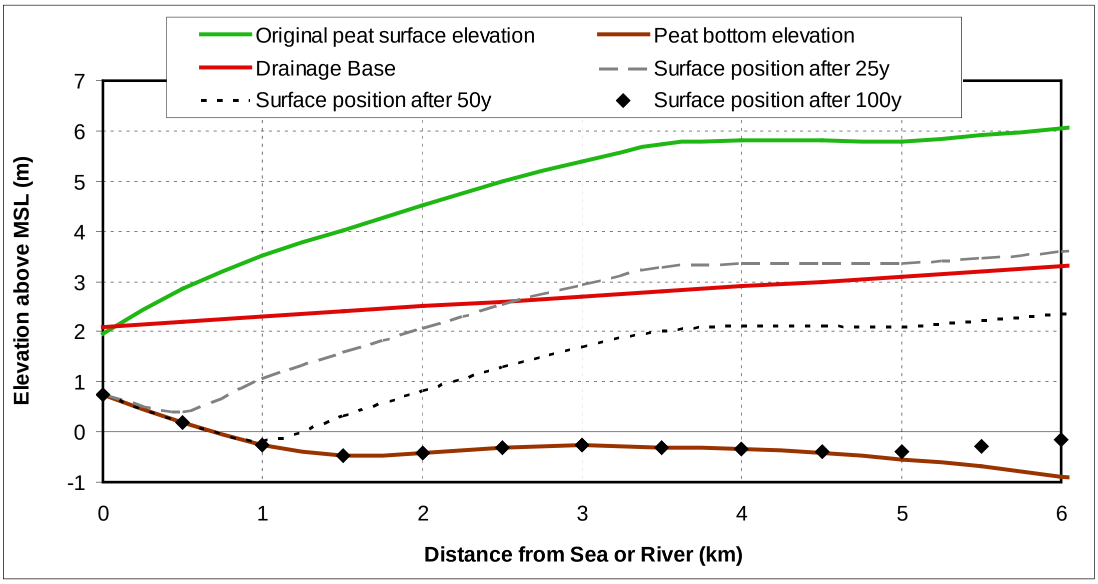

Figure 1 Average cross section over 42 profiles of peatland surface elevation and bottom depth in SE Asia. Projected surface elevations after drainage are also shown, relative to the Drainage Base that defines the start of drainage problems as the peat surface subsides.

METHODS

As no accurate full coverage Digital Elevation Model is available for SE Asian lowlands at present, and the accuracy of peat depth maps is poor (leading to a general underestimation of peat depth), we have used measured cross sections of peat surface and peat depth to define the elevation of the peat surface and peat bottom above sea level. Most cross sections (over 80%) were in forested peatland with limited drainage, representing the situation before subsidence started. Of the 42 cross sections presently included in the analysis, 27 are from Malaysia (all from Sarawak) and 15 from Indonesia (equally from Sumatra and Kalimantan). Of these, 24 were taken from publications (notably Anderson 1964; Staub and Gastaldo, 2003), 14 from presentations and technical reports and 5 are from unpublished databases. The average length of cross sections included in the analysis is 9 km, varying from 2.5 to 24 kilometres; the total cross section length is 377 km.

To test at what point peatland drainability would be seriously affected by subsidence, we defined three threshold levels. Drainability is assumed to end in all cases when the peat surface is at MSL. In near-coastal tidal areas, drainability is affected when the surface is at High Tide level (estimated to be 1.5 m above MSL on average). Further away from the coast or rivers, drainability is affected when the surface approaches a Drainage Base which is defined by adding a conveyance gradient of 0.2 m km^{-1} to High Water Level for river dominated water levels, and to MSL for sea dominated water levels (Fig. 1). The conveyance gradient represents the water table gradient that should be maintained in canals to allow rainfall to be discharged from the land; the value of 0.2 m km^{-1} is a rule of thumb that is often applied in drainage system design and assessment (e.g. DID Sarawak, 2001).

To estimate the time it would take for subsidence to bring peat surface levels to the drainability thresholds, we applied an initial subsidence rate of 1.4 m in the first 5 years, followed by a constant rate of 5 cm y^{-1} in subsequent years (Hooijer et al., 2012). This calculation was done using the 42 individual original profiles.

Figure 1 Average cross section over 42 profiles of peatland surface elevation and bottom depth in SE Asia. Projected surface elevations after drainage are also shown, relative to the Drainage Base that defines the start of drainage problems as the peat surface subsides.

	Malaysia (Sarawak)	Indonesia (Kalimantan + Sumatra)	**Malaysia + Indonesia**
Number of cross sections available	27	15	**42**
Average length of cross sections, from river (km)	7.0	11.5	**9.0**
Average peat depth (m)			
Average peat depth (m)	6.2	7.5	**6.7**
Percentage peat depth > 3m	81%	88%	**83%**
Position of peat surface			
Position above MSL, 1 km from river (m)	3.8	3.1	**3.5**
Position above MSL, 5 km from river (m)	5.9	5.7	**5.8**
Position of peat bottom			
Percentage area where peat bottom below MSL	60	72	**63**
% peat bottom below MSL + Sea Level Rise[a]	67	78	**70**
% peat bottom below High Water Level[b]	83	98	**87**
% peat bottom below Drainage Base[c]	92	99	**94**
Trend in start of serious drainage problems (peat surface below Drainage Base[c])			
Percentage area affected after 25 years	46	49	**46**
% after 50 years	70	70	**69**
% after 100 years	83	92	**85**
Trend in end of gravity drainage (peat surface potentially at Mean Sea Level)			
Percentage area affected after 25 years	12	12	**12**
% after 50 years	32	28	**30**
% after 100 years	52	54	**52**

[a] *A value of 0.5 has been assumed for Sea Level Rise over 100 years (IPCC, 2007)*

[b] *High Water Level: High Tide Level (MSL + 1.5 m) near the Sea, and Bankful Flood Level along inland rivers (as defined by the position of levees in cross sections).*

[c] *The Drainage Base was defined by adding a conveyance gradient of 0.2 m/km to HWL for River dominated water levels, and to MSL for Sea dominated water levels.*

RESULTS AND DISCUSSION

The analysis shows that the peat bottom is below MSL along 63% of the total length of all transects (more if the effect of sea level rise is added), below High Water Level along 87%, and below the Drainage Base along 94% (Table 2). This indicates that at least 63%, of drained peatlands in SE Asia may potentially become undrainable and unproductive. In reality, this number will be higher as drainability often ends when water levels approach the Drainage Base (DB).

According to these data, serious drainage problems will start within 25 years on 46% of drained peatland, and they will affect 69% of the land within 50 years. The onset of frequent inundation as the surface approaches MSL is expected to affect 12% of the land within 25 years and 30% within 50 years. After 100 years, 85% of drained peatland is projected to be below the Drainage Base and 52 % near MSL.

This analysis covers only a relatively small subsample of SE Asian peatlands. The individual cross sections are highly variable in shape, depending on location in the landscape and development history. However Table 2 also shows that the average shape of the cross sections collected in Malaysia is quite similar to the average of those collected in Indonesia, with a peat surface position of 5.9 and 5.7 m above MSL (Mean Sea Level) respectively at 5 km from the nearest river. This could indicate that this tentative dataset may already be considered quite representative for the majority of coastal peat domes in SE Asia. However it is possible that the selected cross sections systematically overestimate peat depth, as the underlying studies often focussed on large peat domes rather than shallow smaller peatlands. This would mean that the actual speed at which peatlands will become undrainable may actually be higher than we find.

It should be noted that the current analysis assumes that subsidence continues at a constant rate of 5 cm/y until the peat is depleted. It is suspected that subsidence rate actually slows down as the lowest few metres of the peat deposit are exposed, which can be more sapric in nature with higher bulk density and mineral content. Subsidence rates in such material tend to be lower than in fibric peat (Hooijer et al. 2011). Work on refining the analysis to account for this effect is ongoing. This will somewhat increase the time period before the peat surface approaches MSL. However it will have less effect on the time period before reaching DB, as at that point there is usually several metres of peat left and the peat at the surface would often still be expected to be fibric in nature (Fig. 1).

Figure 2 Frequently flooded oil palm plantation on a subsided peatland. Total subsidence is likely to have been over 2 metres since drainage in the early 1990s.

CONCLUSION

This tentative analysis confirms that SE Asia will be no exception to the global experience in drained peatlands. We find that serious drainability problems will start in a few decades after the onset of drainage and may lead to the end of agricultural production in between 30% and 69% of the coastal peatlands within 50 years. Eventually, most drained peatlands will inevitably be rendered unproductive.

The higher subsidence rate in SE Asia implies that such problems will be evident much sooner than in cooler temperate climates. In fact, they are already beginning to be observed in some peatland areas which were drained in the early 1990s (Fig. 2), although increasing inundation frequency is so far rarely recognized as being caused by subsidence. Clearly, the decrease in drainability of coastal peatlands will become a major challenge for SE Asia. We propose that in land use planning and economic cost-benefit analyses, the benefits of increasing agricultural productivity on peatlands in the short term should be weighed against the inevitable increase in water management costs, and in many areas the medium-term loss of agricultural production and human livelihoods.

Further work will be required to reduce the uncertainty in these numbers. For a spatially explicit analysis, maps of elevation, peat depth and land cover need to be combined; such work is ongoing.

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